(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
13 December 2001 (13.12.2001)

PCT

(10) International Publication Number
WO 01/94995 A2

(51) International Patent Classification[7]: G02B 6/00

(21) International Application Number: PCT/US01/17725

(22) International Filing Date: 31 May 2001 (31.05.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
09/588,506 5 June 2000 (05.06.2000) US

(71) Applicant: **CALIENT NETWORKS, INC.** [US/US]; 5853 Rue Ferrari, San Jose, CA 95138-1857 (US).

(72) Inventors: **KEATING, Adrian**; Unit #12, 1818 Chapala Street, Santa Barbara, CA 93101 (US). **ERWIN, Bart**; 108 Brandon Drive, Goleta, CA 93117 (US). **WELSH, David**; 20535 Via Talavera, Yorba Linda, CA 92887 (US). **BOWERS, John**; 4601 Sierra Madre, Santa Barbara, CA 93110 (US). **ZHOU, Ping**; 6768 West Aurora Drive, Glendale, AZ 85308 (US). **LEE, Seung, Bok**; 134 Graham Road #1C4, Ithaca, NY 14850 (US). **ANDERSON, Robert**; 893 Cienequitos Road, Santa Barbara, CA 93110 (US). **HELKEY, Roger**; 585 Sycamore Vista, Montecito, CA 93108 (US).

(74) Agents: **MALLIE, Michael, J.** et al.; Blakely, Sokoloff, Taylor & Zafman LLP, 7th Floor, 12400 Wilshire Boulevard, Los Angeles, CA 90025 (US).

(81) Designated States *(national)*: CA, JP.

(84) Designated States *(regional)*: European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR).

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

WO 01/94995 A2

(54) **Title:** FIBER BLOCK CONSTRUCTION FOR OPTICAL SWITCHES AND TECHNIQUES FOR MAKING THE SAME

(57) **Abstract:** Fiber block construction for optical switches and techniques for making the same are disclosed to achieve high positional accuracy for fiber arrays. High positional accuracy is achieved by using fiber plates with tapered holes, using multiple fiber plates to control both position and angle accuracy of fiber arrays, using tapered fibers for easy insertion of fibers into holes of fiber plates, using epoxy to position accurately fiber arrays, using semi-automation to insert accurately fibers into holes of a fiber plate, using a custom fiber input block to correct for lens array position errors, and using stackable plates with grooves to position accurately fiber arrays.

FIBER BLOCK CONSTRUCTION FOR OPTICAL SWITCHES AND TECHNIQUES FOR MAKING THE SAME

FIELD OF THE INVENTION

The present invention relates generally to fiber optics and optical switches. More particularly, the present invention relates to fiber block construction for optical switches and techniques for making the same.

BACKGROUND OF THE INVENTION

An optical switching device couples light beams from an input fiber to an output fiber. Typically, light beams from an input fiber are collimated and directed toward a desired location such as an output fiber. For many optical switching devices, a housing or spacing unit such as a "fiber block" is used to position fibers in an array. A fiber block positions the fibers in an array to produce two-dimensional arrays of light beams or to receive two-dimensional arrays of light beams. The fiber arrays allow for multiple coupling between the input fibers and output fibers.

A problem associated with fiber block construction for optical switches is fiber array position accuracy. That is, if a fiber in a fiber array is not positioned accurately, light beams may be directed or received at an undesirable angle or position. Because light beams may represent data in digital form, the light beams that are directed inaccurately may cause data loss. Thus, to make low-loss optical switches, high fiber array position accuracy is critical in making a fiber block for an optical switch.

SUMMARY OF THE INVENTION

Fiber block construction for optical switches and techniques for making the same are disclosed to achieve high positional accuracy for fiber arrays. High positional accuracy is achieved, e.g., by using fiber

plates with tapered holes, using multiple fiber plates to control both position and angle accuracy of fiber arrays, using tapered fibers for easy insertion of fibers into holes of fiber plates, using epoxy to position accurately fiber arrays, using semi-automation to insert accurately fibers into holes of a fiber plate, using a custom fiber input block to correct for lens array position errors, or using stackable plates with grooves to position accurately fiber arrays.

Other features and advantages of the present invention will be apparent from the accompanying drawings, and from the detailed description, which follows below.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limited in the figures of the accompanying drawings in which like references indicate similar elements and in which:

Figure 1 depicts exemplary fiber blocks and fiber arrays for practicing the invention;

Figure 2 depicts an exemplary face plate for a fiber block;

Figures 3A through **3C** depict exemplary cross-sectional side views of plates, which are used to illustrate techniques for making a face plate with tapered holes;

Figure 4 depicts exemplary top views of a face plate having pyramidal holes;

Figures 5A through **5B** depict illustrations for making a tapered fiber for a fiber array;

Figures 6A through **6C** depict exemplary cross-sectional side views of a fiber block with multiple plates, which are used to illustrate techniques for making a fiber block according to another embodiment;

Figures 7A through **7D** depict exemplary cross-sectional side views of a fiber block with multiple plates, which are used to illustrate techniques for making a fiber block according to another embodiment;

Figures 8A through **8C** depict exemplary cross-sectional side views of a fiber block with multiple plates, which are used to illustrate techniques for making a fiber block according to another embodiment;

Figure 9 depicts one embodiment of a fiber insertion mechanism having a linear translation stage;

Figure 10A through **10B** depict cross-sectional side views of a fiber array, which are used to illustrate techniques for correcting systematic positional errors of a fiber array;

Figure 11 depicts one embodiment of a fiber block having stackable fiber plates;

Figure 12 depicts one embodiment of a fiber block having a face plate with an array of holes;

Figure 13 is a flow chart illustrating one embodiment of an operation for making a fiber block; and

Figure 14 depicts an illustration of an exemplary optical switching system for practicing the invention.

DETAILED DESCRIPTION

Fiber block construction for optical switches and techniques for making the same are described to achieve high positional accuracy for fiber arrays. High positional accuracy is achieved, e.g., by using fiber plates with tapered holes, using multiple fiber plates to control both position and angle accuracy of fiber arrays, using tapered fibers for easy insertion of fibers into holes of fiber plates, using epoxy to position accurately fiber arrays, using semi-automation to insert accurately fibers

into holes of a fiber plate, using a custom fiber input block to correct for lens array position errors, or using stackable plates with grooves to position accurately fiber arrays.

In the following description, a number of techniques are illustrated to provide high positional accuracy for fiber blocks. Such fiber blocks may be used for optical multi-plexing devices and other systems in which two-dimensional array of fibers is required. The following techniques illustrate exemplary methods or processes for making a fiber block, fiber, fiber plate, fiber arrays, or inserting or positioning fibers in a fiber plate or plates.

Fiber Blocks and Lens Arrays

Figure 1 depicts exemplary fiber blocks and fiber arrays for practicing the invention. Referring to **Figure 1**, three-dimensional views 130 and 132 are shown to illustrate an input fiber block 102 and an output fiber block 104. View 130 depicts input fiber "array" block 102 having a face plate 122. Input fiber block 102 is connected with fibers 114. View 132 depicts an output fiber "array" block 104 having a face plate 124. Output fiber block 104 is connected with fibers 116.

Fibers 114 are optical fibers that conduct light beams to input fiber block 102. Fibers 114 may be bundled and feed into input fiber block 102. Input fiber block 102 is a housing or spacing unit for fibers 114. Input fiber block positions fibers 114 accurately in an array for face plate 102. Face plate 122 includes an array of holes arranged to receive fibers 114 from input fiber block 102. Input fiber block 102 positions fibers 114 so that ends of fibers are inserted into a corresponding hole of face plate 122. Fibers 114 allow light beams to pass through input fiber block 102 and out from a hole of face plate 122.

Fibers 116 are optical fibers that conduct light beams for output fiber block 104. Fibers 116 may be bundled and feed into output fiber block 102. Output fiber block 104 is a housing or spacing unit for fibers 116. Output fiber block 104 may also operate as an input fiber block. Furthermore, input fiber block 102 may also operate as an output fiber block. Output fiber block 104 positions fibers 114 into an array for face plate 124. Face plate 124 includes an array of holes arranged to receive fibers 116 from output fiber block 102. Output fiber block 102 positions fibers 116 so that ends of fibers are inserted into a corresponding hole of face plate 124. Fibers 116 allow light beams to pass through a hole of face plate 124 and output fiber block 124.

Figure 1 also illustrates a cross-section side view of an input fiber array 142 and an output fiber array 144. Input fiber array 142 includes an array of optical fibers 110. Fibers 110 include a fiber buffer 124, a cladding 120, and a core 122. Core 122 operates to conduct and transmit light beams. Cladding 120 is configured to have a lower optical index than core 122. As such, cladding 120 operates as a sheath and is able to confine and guide light beams in core 122. Fiber buffer 124 protects cladding 122 and core 120.

For one embodiment, fibers 110 are attached with lens array 106. Alternatively, lens array 106 may be spaced from fibers 110 and positioned in front of fibers 110. Furthermore, a face plate with a plurality of holes may be placed in between fibers 110 and lens array 106. The face plate may be connected with lens array 106. For example, fibers 110 may have ends or tips with exposed cladding 120 and core 122, which pass through holes of the face plate.

Lens array 106 receives light beams from fibers 110 and collimates the light beams. Lens array 106 directs light beams to output fiber array

144. Output fiber array 144 includes an array of fibers 112. Fibers 112 include a fiber buffer 124, cladding 120, and core 122 and operate in the same manner as fibers 110. Fibers 112 are attached with lens array 108. Alternatively, lens array 108 may be unattached with fibers 112 and positioned in front of fibers 112.

Lens array 108 receives collimated light beams from input fiber array 142 and directs the light beams to fibers 112 of output fiber array 144. In the example of **Figure 1**, fiber "B" of fibers 110 outputs a light beam to lens array 106, which collimates the light beam and directs the light beam to lens array 108. Lens array 108 directs the light beam to fiber "B" of fibers 112. Thus, a light beam from an input fiber is directed to an output fiber thereby coupling optically the input fiber and output fiber.

Figure 2 depicts an exemplary face plate 200 for a fiber block. Referring to **Figure 2**, face plate 200 includes a plurality of holes 204 arranged in an array. The array may have any number of configurations, for example, the array may have interleaving holes or a grid of holes. Tips or ends of fibers are inserted into holes 204 of face plate 200 to position the fibers in an array. The tips or ends may include the cladding and core of the fiber such that a fiber buffer does not pass through the holes of face plate 200.

Face plate 200 may be made from silicon material. A blown-up view of section 202 of face plate 200 illustrates a plurality of circular holes 204 for arranging and positioning fibers. Holes 204 may take a variety of shapes and be arranged in a variety of configurations, e.g., holes 204 may have triangular, rectangular, or square shapes.

Tapered Fiber Block Holes

Figures 3A through **3C** depict exemplary cross-sectional side views of plates, which are used to illustrate techniques for making a face plate with tapered holes. Referring to **Figure 3A**, a fiber 302 having a cladding and core 303 may be inserted in a tapered hole for a face plate defined by substrate 303. Because substrate 303 defines a tapered hole, insertion of fiber 302 is made easier.

For one embodiment, to make a tapered hole such as that shown in **Figure 3A**, an etching mask 305 is formed on one side of substrate 303 to define a hole for a face plate. The etching mask may be an oxide layer, a polysilicon layer, polymer layer, nitride layer, or other types of protection layers. Next, the exposed portions of substrate 303 on the bottom side are etched selectively to form a tapered hole. That is, the bottom side of substrate 303 is etched to form a hole having an increasing gap in an upward direction from the bottom side.

For example, to form a tapered hole, a profile control etching process may be used. A profile control etching process such as, for example, a time controlled deep silicon etching process may be used to control the profile of the hole. Alternatively, a deep reactive ion etching (RIE) process may be used in varying time intervals.

For the time controlled etching processes, each successive etching interval is greater in duration than a preceding interval. As such, the beginning of the time-controlled process provides a narrower opening, and, as each interval increases, the time-controlled process provides a wider opening to form a tapered hole. This process continues until a hole is made in substrate 303.

The profile control etching process may also be implemented by increasing selectively etching parameters such as direct current (DC) bias,

RIE power, and gas flow rates. Alternatively, profile control may be achieved by increasing the passivation parameters such as deposition time and passivation gas flow. Furthermore, the micro-loading condition of a silicon etch may be used to induce a tapered profile.

In an alternative embodiment, etch mask 305 may be formed on the topside of substrate 303 instead of the bottom side to form a tapered hole from the topside. For example, the above processes may be used in which decreased time intervals or decreased etching parameters are used to form a hole having a decreasing gap in the downward direction.

The thusly-formed face plate defines a tapered hole for easy insertion of fiber 302. Fiber 302 includes a cladding and core 303 that is inserted in the tapered hole. The cladding and core 303 may protrude from the bottom opening of the hole.

Referring to **Figure 3B**, a fiber 304 having a cladding and core 305 may be inserted into a tapered hole of a face plate defined by two substrates 310 and 312. The cladding and core 305 may protrude from the bottom opening of the hole. Using two substrates increases the effective hole tapering for a face plate. The same processes described in **Figure 3A** may be used to form the tapered holes for substrate 310 and 312. To prevent fiber 304 from hitting the lower substrate 312, the bottom opening of the hole defined by top substrate 310 is slightly smaller than the top opening of the hole defined by lower substrate 312.

Referring to **Figure 3C**, a fiber 306 having a cladding and core 307 is inserted into a hole defined by substrate 316. The hole has a top section with a tapered shape and a bottom section with a straight sidewall shape. The cladding and core 307 may protrude from the bottom opening of the hole.

For one embodiment, an etch mask 314 is formed on one side ("topside") of substrate 316 to define a tapered hole. The exposed portions of the topside of substrate 316 are etched selectively.

The exposed portions of the topside of substrate 316 are etched, e.g., by using the above processes described in **Figure 3A** to define a hole and then enlarged using a crystallographic etching process. For a crystallographic etching process, an etching liquid is used that etches faster along some crystal planes of substrate 316. For example, the etching liquid may be KOH etching solution. The etching substantially stops when left and right etch planes meet. The crystallographic etching process of **Figure 3** produces pyramidal holes in some orientations of silicon crystals.

Next, an etch mask 318 is formed on the other side ("bottom side") of substrate 316 to define a straight side wall hole. The exposed portions of the bottom side are etched using a directional etching process to form a straight side wall hole that meets with the tapered hole. In an alternative embodiment, the straight side wall hole on the bottom side of substrate 316 may be formed before the tapered hole on the top side of substrate 316.

Figure 4 depicts exemplary top views of a face plate having pyramidal holes. For one embodiment, the pyramidal holes shown in **Figure 4** are the top views of the holes formed using the process described in **Figure 3C**. Referring to **Figure 4**, a fiber may be inserted in the pyramidal holes, as shown in the varying top views 402 and 404. The pyramidal holes allow a fiber to be easily inserted into the small opening at the bottom of a face plate.

Fiber Thinning

Figures 5A through **5B** depict illustrations for making a tapered fiber for a fiber array. The techniques for making a tapered fiber for a fiber array allow for easy insertion of a fiber into holes of a fiber or face plate. For example, the diameter at one end of a fiber is decreased, which provides a tapered shape for easy insertion of a fiber into holes of a fiber plate.

Referring to **Figure 5A,** a fiber 522 is inserted into an etchant solution 524. For example, fiber 522 may be inserted into an etchant solution such as hydro fluoric (HF) acid, which controllably dissolves the fiber material. Fiber 522 is made of a material that dissolves or is removed easily in etchant solution 524.

Referring to **Figure 5B**, the diameter of the end of fiber 522 is decreased uniformly by slowly removing the end of fiber 522 from the etchant solution 524 at a controlled rate to minimize steps in the fiber width between etched and unetched regions of fiber 522. The thusly-formed fiber 522 has a decreased diameter or a tapered end, which allows for easy insertion of a fiber into a hole of a fiber plate.

Fiber Array Loading

Figures 6A through **6C** depict exemplary cross-sectional side views of a fiber block with multiple plates, which are used to illustrate techniques for making a fiber block according to another embodiment.

Referring to **Figure 6A**, initially, two silicon array plates 602 and 604 are used for a face plate. For one embodiment, the lower plate 604 defines tapered holes such that the tapered holes have an upper opening (toward fibers 606) wider than a lower opening (away from fibers 606). The back plate 602 also defines tapered holes such that the tapered holes have an upper opening wider than a lower opening. The back plate 602

has tapered holes with bottom openings larger than the bottom openings of the tapered holes for lower plate 604 to reduce the tolerance for fiber insertion. The ends or tips (cladding and core 620) of fibers 606 are inserted into the holes of back plate 602 and lower plate 604 in groups or one at time until the plates are fully populated with fibers.

Referring to **Figure 6B**, the back plate 602 is then pulled back along the cladding and core 620 of fibers 606. The clearance of the openings for the back plate 602 allows the plates to be separated without significant stress to fibers 606. Back plate 602 also serves to reduce the angular spread of the cladding and core 620 of fibers 606 exiting from the lower plate 604.

Referring to **Figure 6C**, the fixture or block (not shown) housing the structure of **Figure 6** is then filled with an adhesive material. For example, an epoxy 622 may be used to fill the holes of plates 602 and 604. For one embodiment, a vacuum may be used to draw epoxy 620 through the holes of lower plate 604 and back plate 602.

For one embodiment, epoxy 622 between plates 602 and 604 has a low viscosity to hold fibers 606 in plates 602 and 604. This allows the holes of plates 602 and 604 to be only slightly larger than the diameter of fibers 606, which leads to fiber placement closer to the center of the holes. For another embodiment, epoxy 622 above back plate 602 may have a high viscosity to seal the back end of the plates in order to minimize the loss of low viscosity epoxy in between the plates.

At this stage, fibers 606 have cladding and core 620 protruding from epoxy 622 and holes of lower plate 604. After epoxy 620 sets, the excess cladding and core 620 of fibers 606 are removed. For example, a saw may be used to cut through epoxy 622 and cladding and cores 620 protruding from lower front plate 604 to provide a uniform surface,

which may the be polished until it is optically flat within a small fraction of an optical wavelength. The polishing process is to minimize scratches on the surface of the fiber array.

Buffer Capture

Figures 7A through **7D** depict exemplary cross-sectional side views of a fiber block with multiple plates, which are used to illustrate techniques for making a fiber block according to another embodiment.

For one embodiment, an alternative to the fiber array loading techniques, as illustrated in **Figures 6A** through **6C**, is to use a plate that locates the fibers using the fiber buffer on the outside of the fibers. That is, optical fibers often include a number of layers. For example, a fiber may include an inner glass layer referred to as the "core." The core is surrounded by a sheath or cladding to that serves to confine light in the core. The cladding typically has a lower optical index than the core. The cladding is surrounded by a fiber buffer that provides strength and prevents damage to the cladding and core.

Referring to **Figure 7A**, fibers 702 are inserted into tapered holes of a first plate 710. For example, fibers 702 may be positioned in a two dimensional array using first plate 710. The end sections of fibers 702 protrude away from the holes of first plate 710.

Referring to **Figure 7B**, the outer material or "fiber buffer" of the protruding sections of fibers 702 is removed. For example, the "fiber buffer" is removed from the protruding ends to expose the cladding and core 720. For one embodiment, the fiber buffer is removed chemically by using acetone or a stripping solution (e.g., a paint stripper solution). After the fiber buffer is removed, the cladding and core 720 is exposed and protrudes away from the holes in first plate 710.

Referring to **Figure 7C**, the cladding and core 720 of fibers 702 may be etched to have a thinner, tapered, or pointing tip. By having a thinner, tapered, or pointing tip for cladding and core 720, the cladding and core 720 may be inserted easily into a second plate 712. This step, however, may be omitted and cladding and core 720 may retain its original shape.

Referring to **Figure 7D**, the cladding and core 720 of fibers 702 are inserted into tapered holes of a second plate 712. The second plate 712 is pushed above the tips of the cladding and core 720. Second plate 712 operates to position precisely fibers 702 into the fiber array. Alternatively, fibers 702 may be attached to second plate 712 by using an epoxy process. For example, the techniques illustrated in **Figure 6C**, may be used to attach first and second plates 710 and 712 to cladding and core 720 of fibers 702. In addition, the excess fiber removal and polishing process techniques, as illustrated in **Figure 6C**, may be used to cut and polish the ends of cladding and core 720 of fibers 702 to provide an optically smooth surface.

Multi-Fiber Plates

Figures 8A through **8C** depict exemplary cross-sectional side views of a fiber block with multiple plates, which are used to illustrate techniques for making a fiber block according to another embodiment. The following techniques use at least three fiber plates. An outer plate 804, middle plate 806, and inner plate 810. A second or extra middle plate may also be used such as middle plate 808. For one embodiment, the fiber plates may define a gap having "U" shape in which a fiber is inserted.

Referring to **Figure 8A**, prior to inserting fibers 802 into the fiber plates, the fiber buffers of the end sections of fibers 802 are removed to expose cladding and core 820. For example, the techniques illustrated by

Figures 7A and **7B** may be used to remove the fiber buffer to expose the cladding and core. Fibers 802 are then inserted individually or in groups into outer plate 804, which has an upper opening diameter slightly greater than the diameter of the fiber buffer of fibers 802. Outer plate 804 determines the position of fibers 802.

The fiber buffer portion of fibers 802 is then pushed through middle plate 806, which also has holes with a diameter slightly greater than diameter of the fiber buffer. The distance from the outer plate 804 to middle plate 806 (L_1) must be small enough so that fibers 802 cannot pass from one hole in outer plate 804 to an adjacent hole in middle plate 806, but large enough to achieve tight of the fiber angle. Once the fiber buffer portions of fibers 802 are held by outer plate 804 and middle plate 806, the fiber angle of fibers 802 is well controlled. As fibers 802 are inserted, fibers 802 may be further guided by an optional middle plate 808.

Referring to **Figure 8C**, fibers 802 are inserted further until the cladding and core 820 is captured by inner plate 810, which has an upper opening diameter slightly larger than the diameter of fiber cladding and core 820 of fibers 802. Inner plate 810 include holes having an tapered upper opening, which is larger in diameter than the diameter of the fiber buffer of fibers 802. The tapered holes may be formed using techniques as illustrated in **Figure 3C**. The cladding and core 820 of fibers 802 are inserted into the tapered opening of inner plate 810. For one embodiment, the fiber buffer is removed from a region that is shorter than the spacing between the first middle fiber plate and inner fiber plate ($L_2 + L_3$) so a large spacing is desirable to allow stripping the buffer from a reasonable length of fiber.

Fiber Insertion Semi-Automation

Figure 9 depicts one embodiment of a fiber insertion mechanism having a linear translation stage for the purpose of automating fiber insertion. Referring to **Figure 9**, fiber insertion mechanism 900 includes a linear translation stage 904 having a grooved support 914 to support fibers 906, fiber plate 912 with holes for receiving fibers 906, and a two-dimensional translation stage 902.

Fibers 906 are inserted into the holes of fiber plate 912 by linear translation stage 914 that can move fibers 906 into the holes of fiber plate 912. Fiber plate 912 is supported by two-dimensional translation stage 902 that can translate fibers 906 in two dimensions perpendicular to the fiber axis.

For one embodiment, a computer may be used to control movement in steps to move linear translation stage 904 such that fibers 906 are inserted into the holes of fiber plate 912. For example, a computer may control movement of linear translation stage 914 in small incremental steps in a horizontal direction corresponding to the space between fibers in fiber plate 912. Alternatively, a computer may control movement of linear translation stage 914 in a horizontal direction and changing moving two-dimensional stage 902 in both a horizontal and vertical direction. The incremental steps may be made larger if multiple fibers are inserted into fiber plate 912.

For an alternate embodiment, a camera 910 may be used at the input of fibers 906 to view the position of fibers 906 and at the output such that successful insertion of fibers 906 is achieved. Camera 910 may also be used for fine adjustment of the relative position of fibers 906 to fiber plate 912. For example, camera 910 may be used at the output of

fiber plate 912 to verify correct insertion of fiber 906 into the holes of fiber plate 912.

Lens Array Error Correction

Figure 10A through **10B** depict cross-sectional side views of a fiber array, which are used to illustrate techniques for correcting systematic positional errors of a lens array. For one embodiment, lens array 1010 is formed by etching selectively a semiconductor substrate. Such a process can produce very accurately positioned lenses. The masks used to form the lens array can form accurate lenses. However, a small in mask alignment may cause non-uniformity in etching of the lenses from the semiconductor substrate. For example, systematic position errors in molded lens array 1010 may cause random lens position errors.

Referring to **Figure 10A**, a uniform fiber input block 1020 having fibers 1012 is shown. Fibers 1012 output light beams to molded lens array 1010. To illustrate a lens position error, molded lens array 1010 forms non-parallel output beams 1004, which in turn produce optical loss as a result of a light beam being directed to an undesirable position.

Referring to **Figure 10B**, systematic position errors may be corrected by designing a re-aligned uniform fiber input block 1022 to have approximately the same position error of molded lens array 1010 so that light beams from fibers 1012 are directed to the center of the lenses of molded lens array 1010 and produce parallel output beams 1006 directed to a desired position. Thus, for this technique, a custom fiber block mask is formed to correct for varying positional errors in molded lens array 1010.

For one embodiment, a fiber array is aligned with the lens array by adjusting the alignment of holes in a fiber plate. Alternatively, the lens array can be adjusted to the alignment of the holes in the fiber plate. The

lens array can be attached to the fiber array or plate with an adhesive material after alignment. For example, an epoxy may be used to attach the lens array to the fiber array or plate. For another embodiment, a lens array is aligned with a fiber array by observing the positions of beams while the lens array is moved with respect to the fiber array.

Stackable Channel Plates

Figure 11 depicts one embodiment of a fiber block having stackable fiber plates. Referring to **Figure 11**, fiber block 1100 includes a plurality of stackable fiber plates 1110 through 1119. Each stackable fiber plate is formed to have square shaped grooves to position fibers 1120. Alternatively, the stackable fiber plates may have varying shaped grooves, e.g., the stackable fiber plates may have "V" shaped grooves to position fibers 1120. Stackable fiber plates 1110 through 1119 position fibers 1120 into a two-dimensional array. A cladding and core 1104 of each of the fibers 1120 protrudes from an opening defined by the stackable fiber plates.

A technique for making a fiber block repeats the following process until a desired dimension is achieved. For example, a plurality of fibers 1120 may be placed in the grooves of stackable plate 1110. Stackable fiber plate 1112 is then placed on top of stackable fiber plate 1110. Fibers are then placed in the grooves of stackable fiber plate 1112. This process continues until fibers are placed in the grooves of stackable fiber plate 1119. Thus, a fiber block is formed to position fibers in a two-dimensional array using stackable fiber plates.

Figure 12 depicts one embodiment of a fiber block having a face plate with an array of holes. Referring to **Figure 12**, a housing unit 1204 includes a plurality of stackable fiber plates such as stackable fiber plates 1110 through 1119. A face plate 1202 having a plurality of holes 1208 is

attached to the housing unit 1204. The face plate 1202 may be formed using any of the afore-mentioned techniques to form tapered holes to aid the insertion of fibers into holes 1208. The plurality of holes 1208 correspond to fibers placed in the grooves of the stackable fiber plates. For example, cladding and core 1104 may protrude from holes 1208. Thus, fiber block 1200 may be an input fiber block for outputting light beams from an input fiber or an output fiber block for receiving light beams into an output fiber.

Figure 13 is a flow chart illustrating one embodiment of an operation for making a fiber block.

Initially, the following operation begins at operation 1304. At operation 1304, a face plate is inserted into a container. For example, a face plate 1208 is inserted into a container to support face plate 1208.

At operation 1306, multiple channel plates are stacked in the container. For example, stackable fiber plates 1110 through 1119 are stacked in the container, which will be attached with face plate 1208.

At operation 1308, a plurality of optical fibers are inserted into the multiple channel plates. For example, fibers are inserted into the holes formed by the grooves in the stacked fiber plates from a back end.

At operation 1310, the container is agitated or "shaken" until the holes of the two-dimensional hole array are filled. For example, the fibers may move down the grooves in the stacked fiber plates 1110 thorough 1119. For one embodiment, the container is agitated until the core or clad 1104 protrude form holes 1208 of face plate 1202. For an alternate embodiment, an adhesive material such as, for example, epoxy may be deposited in the grooves by agitating the container. The epoxy aids in the positioning of the fibers.

For one embodiment, the protruding ends of the fibers are inserted into holes of face plate 1202. For example, the stackable plates may be moved as a group to insert the fibers into the holes of face plate 1202. Alternatively, the stackable platelets may be placed on a linear moving stage such as that shown in **Figure 9** to move fibers into holes of face plate 1202.

Hence, the above operation forms a fiber block by inserting fibers into fibers plates after the fiber plates have been stacked. The stacked fiber plates have grooves, which forms holes for the fibers to pass through.

Figure 14 illustrates an exemplary optical switching system 1400 for practicing the invention. For example, optical switching system 1400 may represent a 3-dimensional optical switching system. A 3-dimensional optical switching system allows for optical coupling between input fibers and output fibers in different planes using lens arrays and mirror arrays. The lens arrays and mirror arrays provide proper angle and position of light beams traveling from input fibers to output fibers. That is, a light beam must leave and enter a fiber in a direct path.

In the following description of **Figure 14,** mirror arrays are described as micro-electro-mechanical-system (MEMS) mirror arrays. MEMS mirror arrays are arrays of microscopic mirror devices formed with a substrate using integrated (IC) fabrication techniques. The mirror devices can redirect beams of light to varying positions.

Referring to **Figure 14**, optical switching system 1400 includes input fiber "block" array 1450, first lens array 1430A, first MEMS mirror array 1420A, second MEMS mirror array 1420B, second lens array 1430B, and output fiber "block" array 1460.

Input and output fiber "block" arrays 1450 and 1460 may be constructed using any of the techniques illustrated in **Figures 1** through **13**. For example, input and output fiber arrays 1450 and 1460 may be constructed using fiber plates with tapered holes, using multiple fiber plates to control both position and angle accuracy of fiber arrays, using tapered fibers for easy insertion of fibers into holes of fiber plates, using epoxy to position accurately fiber arrays, using semi-automation to insert accurately fibers into holes of a fiber plate, using a custom fiber input block to correct for lens array position errors, or using stackable plates with grooves to position accurately fiber arrays.

Input fiber array 1450 provides a plurality of optical fibers 1440 for transmitting light to first lens array 1430A. First lens array 1430A includes a plurality of optical lenses, which are used to direct collimated beams of light from input fiber array 1450 to individual MEMS mirror devices 1410 on MEMS mirror array 1420A. First lens array 1430A may be connected with input fiber array 1450 or first lens array 1430A may be a separate unit placed in front of input fiber array 1450.

MEMS mirror array 1420A includes a plurality of electrically addressable MEMS mirror devices 1410. For example, MEMS mirror device 1410 may be a gimbaled mirror device having a rectangular, elliptical, or circular shape. MEMS mirror device 1410 may have other shapes or configurations to redirect beams of light. The plurality of MEMS mirror devices 1410 for MEMS mirror array 1420A can pivot a mirror component to redirect or reflect beams of light to varying MEMS mirror devices on second MEMS mirror array 1420B. Second MEMS mirror array 1420B also includes a plurality of MEMS mirror devices such as a MEMS mirror device 1410, which are used to redirect and reflect light beams to varying lenses on second lens array 1430B.

Second lens array 1430B accepts collimated light beams from second MEMS mirror array 1420B and focuses the light beams to individual output fibers 1470 of output fiber array 1460. Second lens array 1430B may be connected with input fiber array 1460 or second lens array 1430B may be a separate unit placed in front of output fiber array 1460.

Optical switching system 1400 allows light beams from any input fiber 1440 of input fiber array 1450 to be redirected to any output fiber 1470 of output fiber array 1460 by changing the angle of mirrors 1410 in mirror arrays 1420A and 1420B. For example, a light beam following the path "A" is outputted from one input fiber and is redirected using first lens array 1430A, second lens array 1430B, and MEMS mirror arrays 1420A and 1420B to a different output fiber . The lens arrays and MEMS mirror arrays may also be used in scanning systems, printing systems, display systems, and other systems that require redirecting beams of light.

Thus, fiber block construction for optical switches and techniques for making the same have been described to position accurately fibers in fiber arrays.

In the foregoing specification, the invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set forth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

CLAIMS

What is claimed is:

1. A fiber block comprising:
at least one fiber plate, each fiber plate defining a plurality of holes, and each hole having a wider top opening than a bottom opening.

2. The fiber block of claim 1, further comprising:
an array of fibers, each fiber having an end section that is inserted into a hole of the fiber plate.

3. The fiber block of claim 2, wherein the end section includes a cladding and a core.

4. The fiber block of claim 2, wherein the end section is tapered.

5. The fiber block of claim 2, further comprising:
an adhesive material holding the array of fibers to the fiber plate.

6. The fiber block of claim 1, wherein each fiber plate defines a plurality of tapered shaped holes.

7. The fiber block of claim 1, wherein each hole has a top section having a tapered shape and a bottom section having a straight-sidewall shape.

8. The fiber block of claim 1, wherein each hole has a pyramidal shape.

9. The fiber block of claim 1, wherein the fiber plate includes:

a first plate defining a plurality of tapered holes; and

a second plate formed adjacent to the first plate, the second plate defining a plurality of tapered holes.

10. The fiber block of claim 9, wherein a top opening of the tapered holes of the first plate is wider than a top opening of the tapered holes of the second plate.

11. The fiber block of claim 9, wherein a bottom opening of the tapered holes of the first plate is wider than a bottom opening of the tapered holes of the second plate.

12. The fiber block of claim 1, wherein the fiber plate includes:

an outer plate defining a plurality of holes;

a middle plate defining a plurality of holes; and

an inner plate defining a plurality of tapered holes.

13. The fiber block of claim 12, further comprising:

an array of fibers, each fiber passing through the holes of the outer plate and the middle plate and an end section of each fiber passing through the tapered holes of the inner plate.

14. A method of positioning fibers, the method comprising:

inserting fibers into tapered holes of a fiber plate.

15. The method of claim 14, wherein inserting fibers includes inserting fibers into the tapered holes to form a fiber array.

16. The method of claim 14, further comprising

planarizing ends of the fibers protruding from the tapered holes of the fiber plate.

17. The method of claim 16, wherein planarizing ends of the fibers includes polishing the ends of the fibers protruding from the tapered holes of the fiber plate.

18. A fiber comprising:

an end section, the end section having a tapered shape.

19. The fiber of claim 18, wherein the end section is inserted into a hole of a face plate.

20. A method of positioning fibers, the method comprising:

inserting fibers having tapered ends into holes of a fiber plate.

21. The method of claim 20, wherein inserting fibers includes inserting fibers into the holes to form a fiber array.

22. The method of claim 20, further comprising:

planarizing ends of the fibers protruding from the holes of the fiber plate.

23. The method of claim 22, wherein planarizing of ends of the fibers includes polishing the ends of the fibers protruding from the holes of the fiber plate.

24. A face plate comprising:

a plurality of holes, each hole having an upper opening that is substantially square and a bottom opening that is substantially circular.

25. The face plate of claim 24, wherein each hole provides a pyramidal shape.

26. A fiber block comprising:

a plurality of plates, each plate defining a plurality of holes; and

a plurality of fibers, each fiber having an upper portion and a lower portion, the upper portion having a larger diameter than the lower portion, and the lower portion of each fiber is inserted into the holes of the plates.

27. The fiber block of claim 26, wherein each plate defines a plurality of tapered holes.

28. The fiber block of claim 26, wherein each tapered hole has an upper opening that is wider than a bottom opening.

29. The fiber block of claim 26, wherein the upper portion of each fiber includes a fiber buffer, fiber cladding, and fiber core.

30. The fiber block of claim 26, wherein the lower portion of each fiber includes a cladding and a core.

31. The fiber block of claim 26, wherein the plurality of plates define a gap between each plate.

32. The fiber block of claim 31, wherein the gap between the plates is increased after fibers are inserted.

33. The fiber block of claim 26, wherein the plates are held in an outer housing that is filled with epoxy.

34. The fiber block of claim 33, wherein the epoxy includes an upper portion having a lower viscosity and a bottom portion having a higher viscosity.

35. The fiber block of claim 33, wherein the epoxy includes an upper portion having a low drying characteristic and a bottom portion having a high drying characteristic.

36. A fiber block comprising:

a plurality of stackable plates, each plate having grooves formed therein, the grooves forming holes for insertion of fibers.

37. The fiber block of claim 36, wherein the grooves are square shaped, "V" shaped, or semi-circular shaped.

38. A method of making a fiber plate, the method comprising:

forming a pattern on a first side of a substrate such that the pattern is used to define a hole; and

removing selectively exposed portions of the substrate defined by the pattern to form a hole having a wider top opening than a bottom opening.

39. The method of claim 38, wherein removing selectively includes forming a tapered hole.

40. The method of claim 38, wherein removing selectively exposed portions includes using a crystallographic etching process.

41. The method of claim 38, wherein removing selectively exposed portions includes increasing or decreasing etching time in intervals to provide a tapered shape hole.

42. A method of aligning a lens array with a fiber array, the method comprising:

observing a position of light beams from the fiber array with respect to the lens array; and

aligning the fiber array or lens array to correct for inaccurate observed light beams.

43. The method of claim 42, wherein observing a position includes observing a position with a camera.

44. The method of claim 42, further comprising:
attaching the lens array to the to the fiber array with an adhesive material.

45. The method of claim 44, wherein the adhesive material is an epoxy.

46. A method of constructing a fiber array, the fiber array having a face plate including a plurality of holes and a plurality of plates with grooves to receive a support fibers, the method comprising:
inserting fibers into square shaped grooves, "V" shaped grooves, or round shaped grooves of the plates.

47. The method of claim 46, further comprising:
moving the plurality of plates toward a face plate having a plurality of tapered holes such that ends of the fibers are inserted into tapered holes of the face plate.

48. The method of claim 47, wherein moving the plurality of plates includes moving the plurality of plates using a linear translation stage.

49. A method for forming a fiber, the method comprising:
forming a tapered end of a fiber.

50. The method of claim 49, wherein forming a tapered end includes:

inserting the end into a solution that controllable dissolves a fiber material; and

withdrawing the end at a controlled rate.

51. The method of claim 50, wherein the solution is hydro fluoric acid.

52. An optical switch, comprising:

an input fiber block configured with a face plate defining a plurality of tapered holes and an array of bi-directional optical fibers, each end of the fibers being inserted into a tapered hole of the face plate;

a first array configured to collimate light beams from the fibers of the input fiber block;

a first and second mirror array configured with a plurality of mirror devices for redirecting beams light, the first mirror array configured to redirect light beams from the first lens array to the second mirror array;

a second lens array configured to collimate light beams being redirected from the second mirror array; and

an output fiber block configured with a face plate defining a plurality of tapered holes and an array of bi-directional optical fibers, each end of the fiber being inserted into a tapered hole of the face plate and configured to receive light beams from the second lens array.

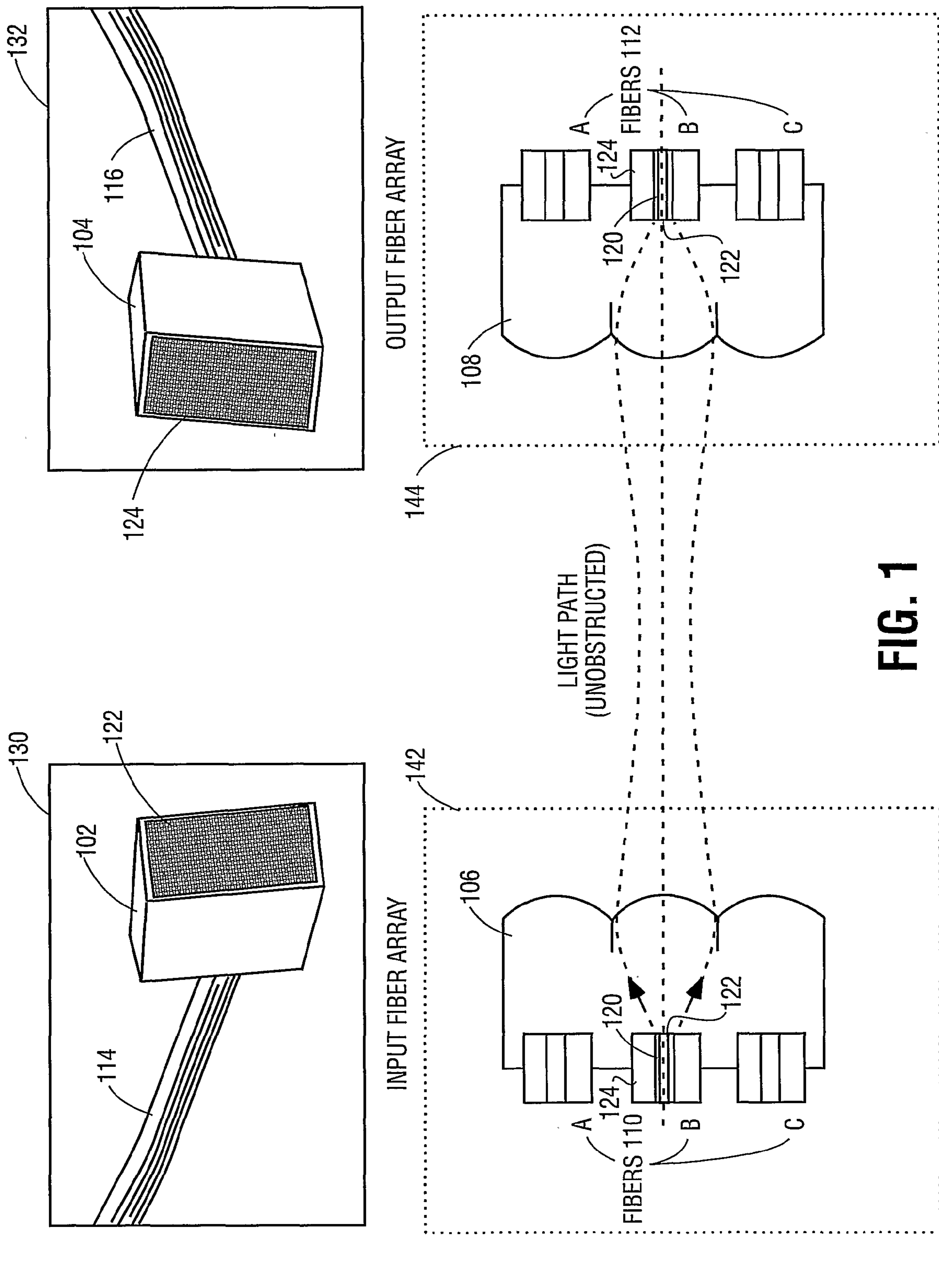

130
102
122
114
132
104
116
124
INPUT FIBER ARRAY
106
120
122
124
A
B
C
FIBERS 110
142
LIGHT PATH
(UNOBSTRUCTED)
OUTPUT FIBER ARRAY
108
120
122
124
A
B
C
FIBERS 112
144

FIG. 1

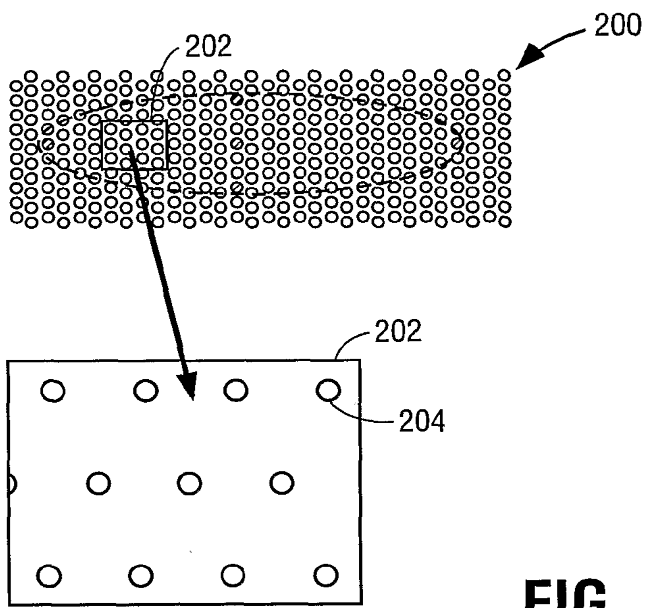


FIG. 2

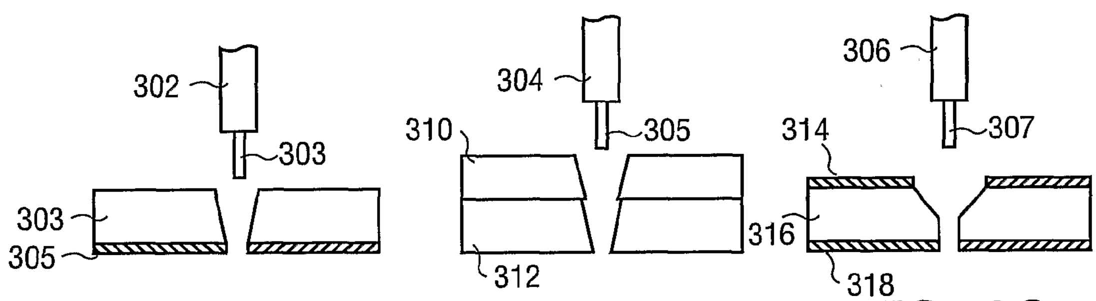


FIG. 3A FIG. 3B FIG. 3C

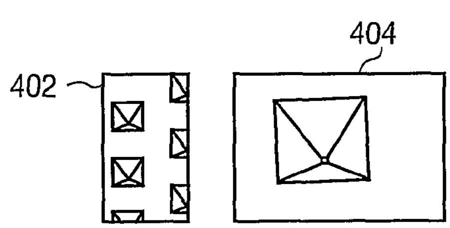


FIG. 4

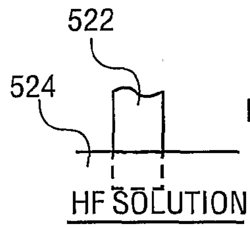


FIG. 5A

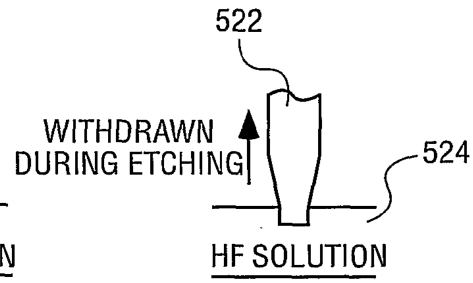


FIG. 5B

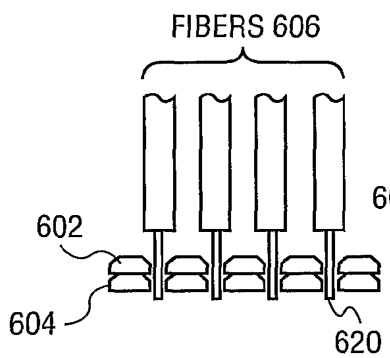


FIG. 6A

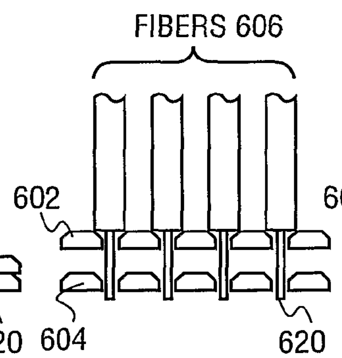


FIG. 6B

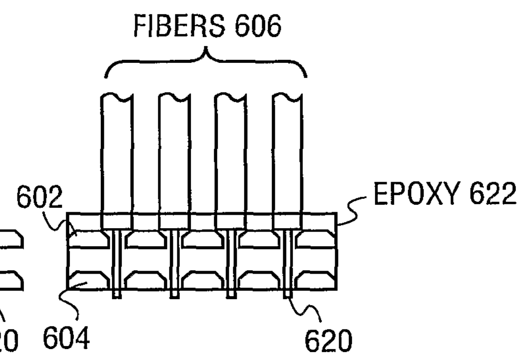


FIG. 6C

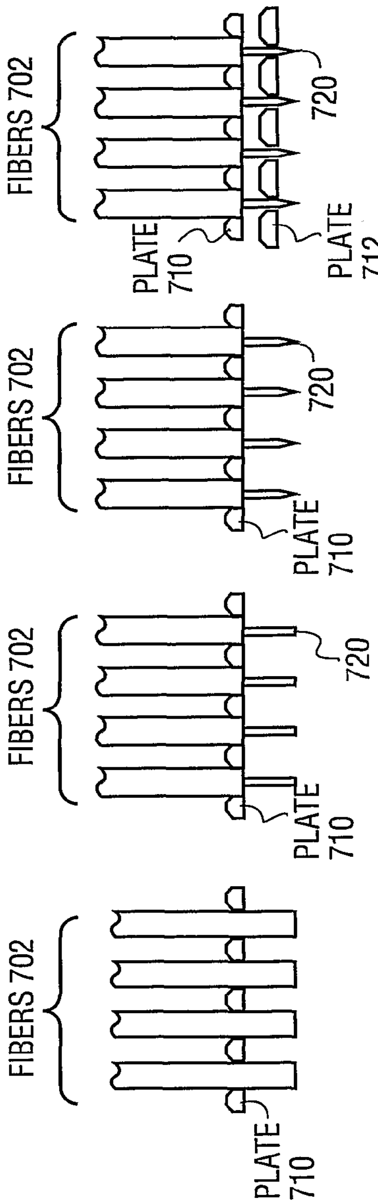


FIG. 7A FIG. 7B FIG. 7C FIG. 7D

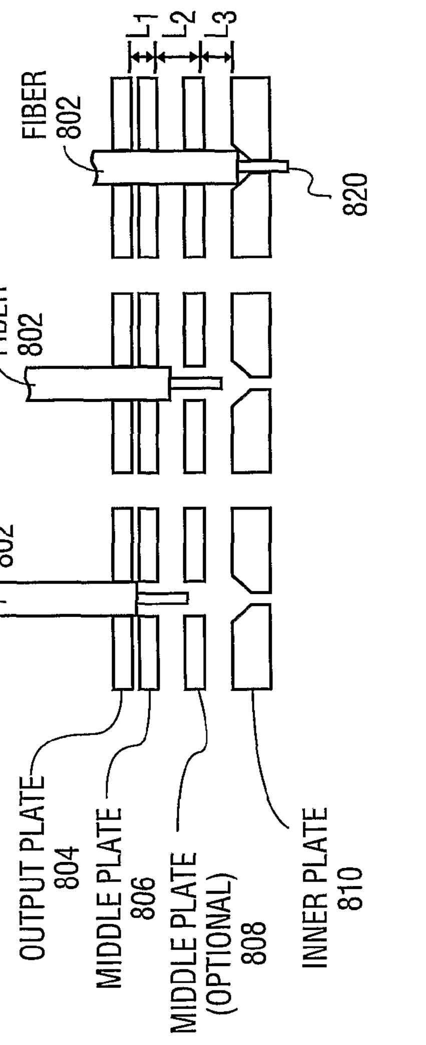


FIG. 8A FIG. 8B FIG. 8C

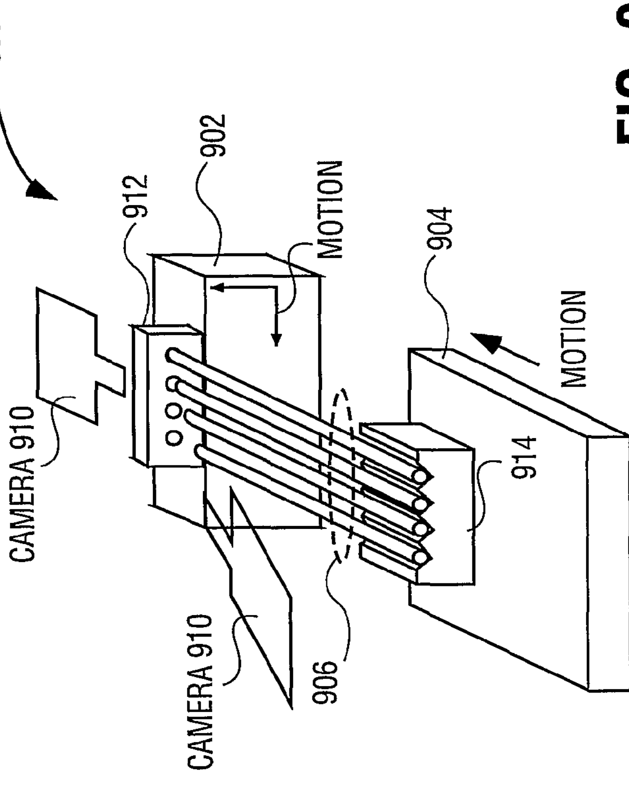


FIG. 9

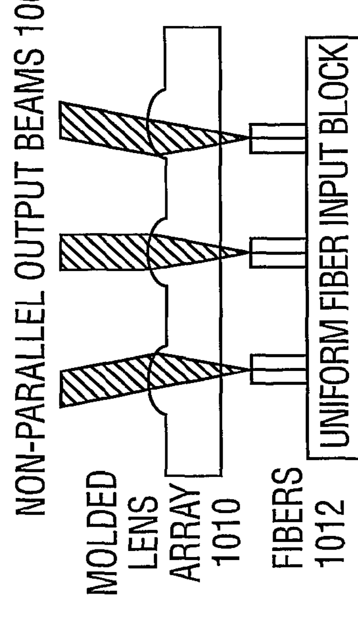


FIG. 10A

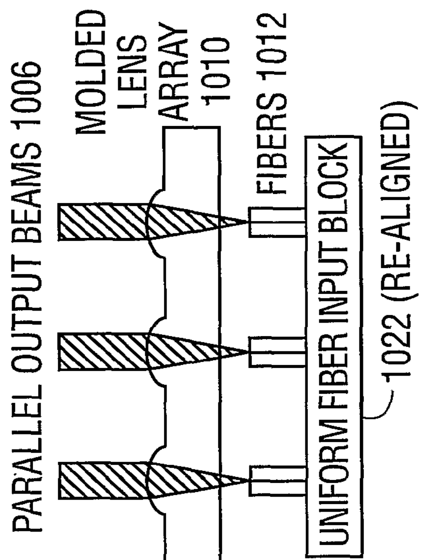
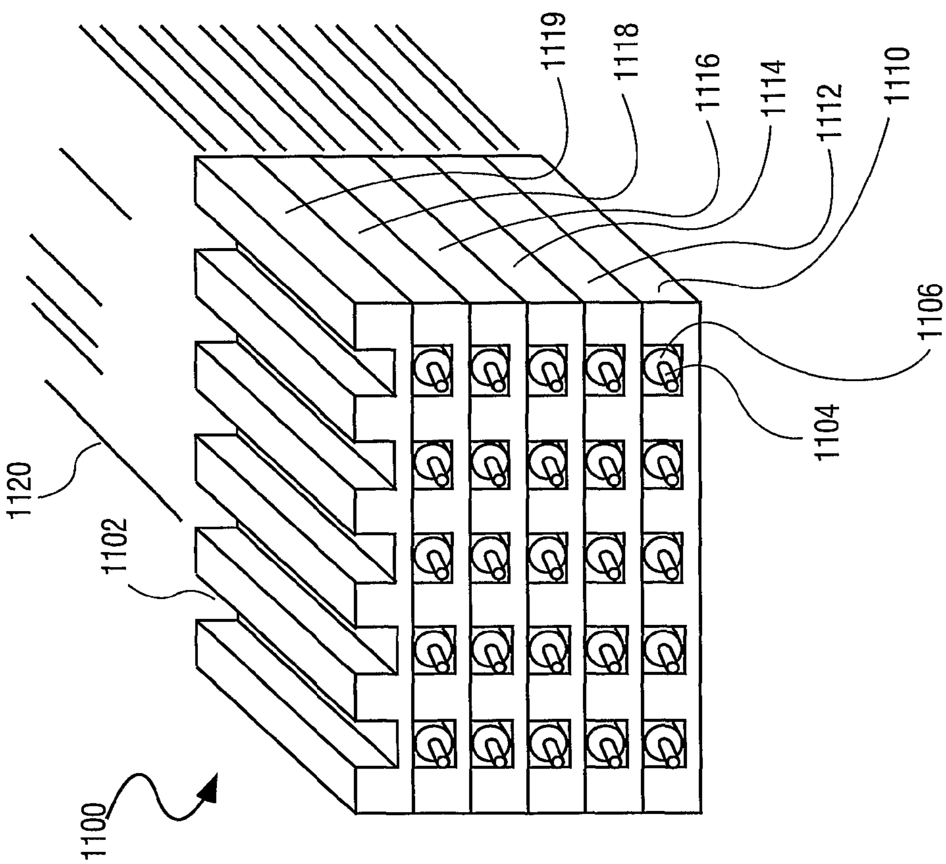


FIG. 10B

FIG. 11



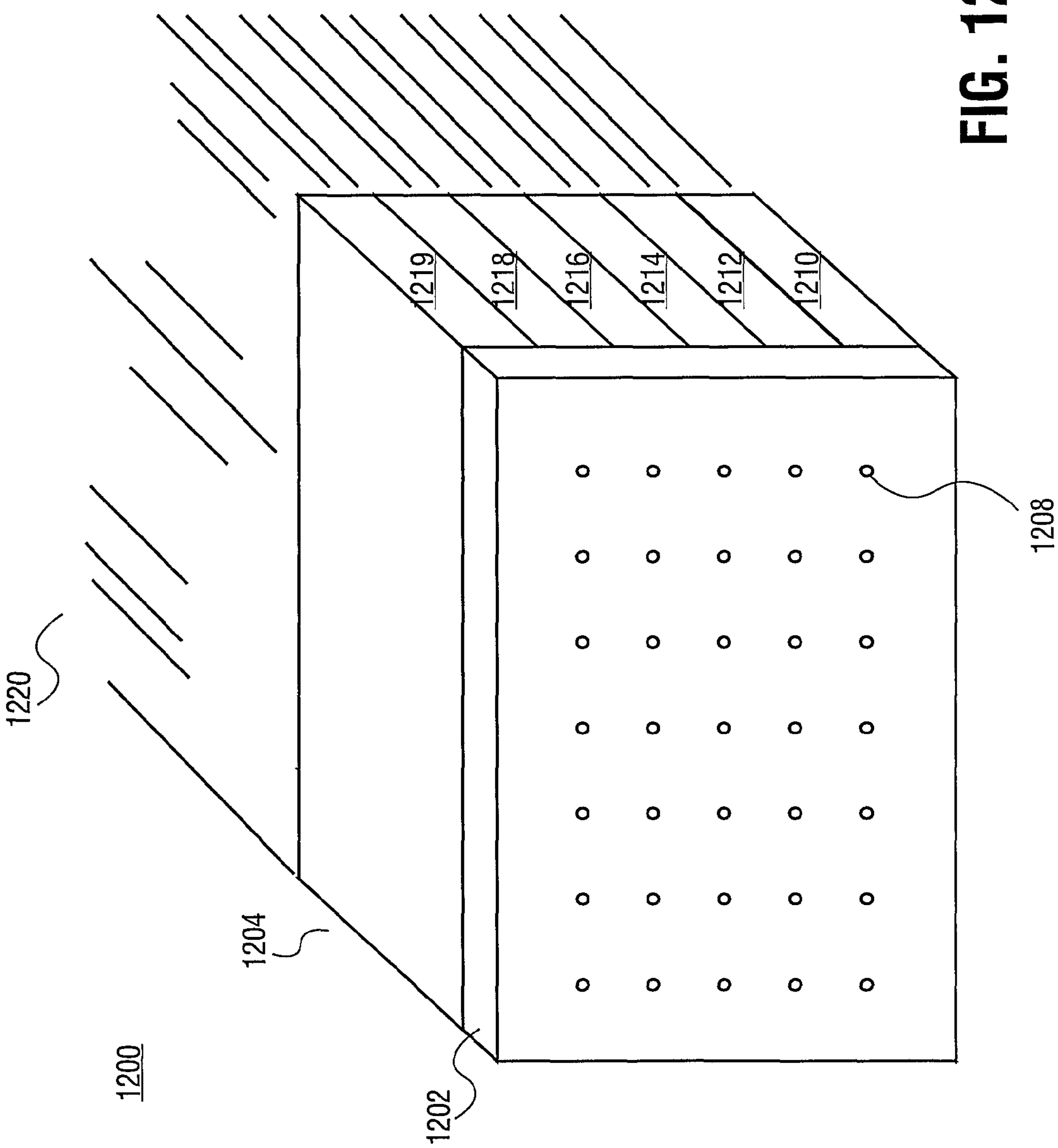


FIG. 12

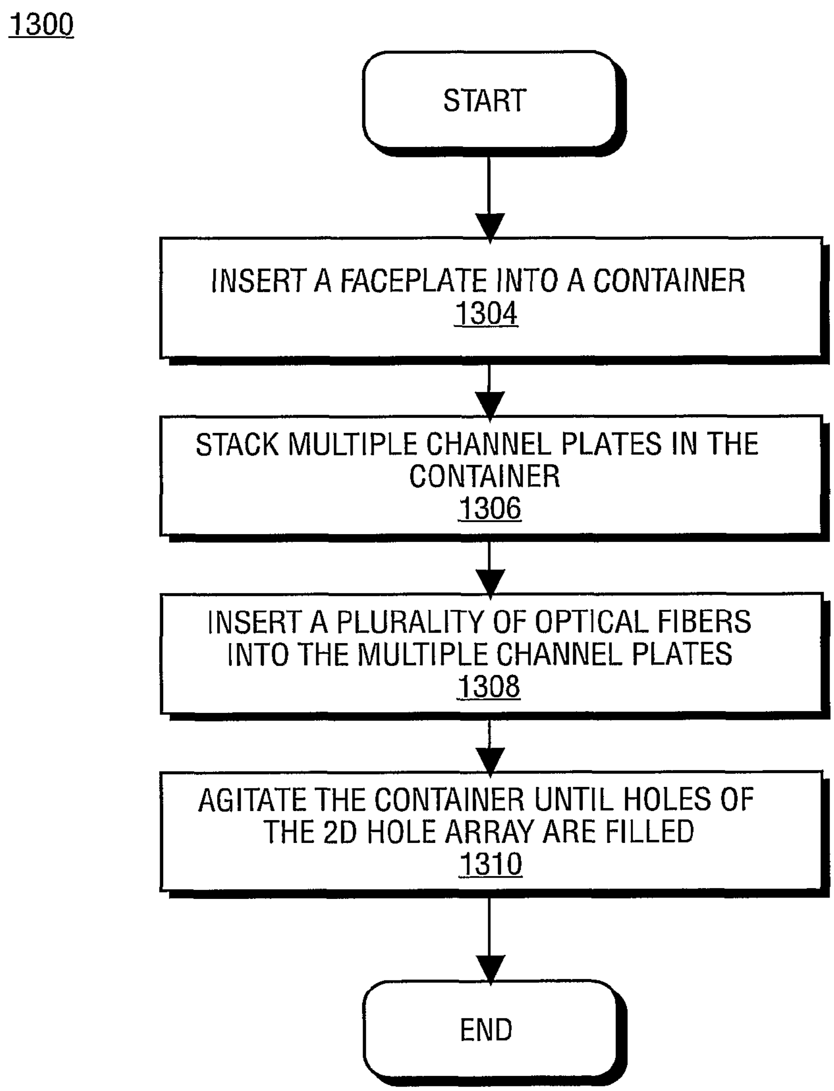

1300
START
INSERT A FACEPLATE INTO A CONTAINER
1304
STACK MULTIPLE CHANNEL PLATES IN THE CONTAINER
1306
INSERT A PLURALITY OF OPTICAL FIBERS INTO THE MULTIPLE CHANNEL PLATES
1308
AGITATE THE CONTAINER UNTIL HOLES OF THE 2D HOLE ARRAY ARE FILLED
1310
END

FIG. 13

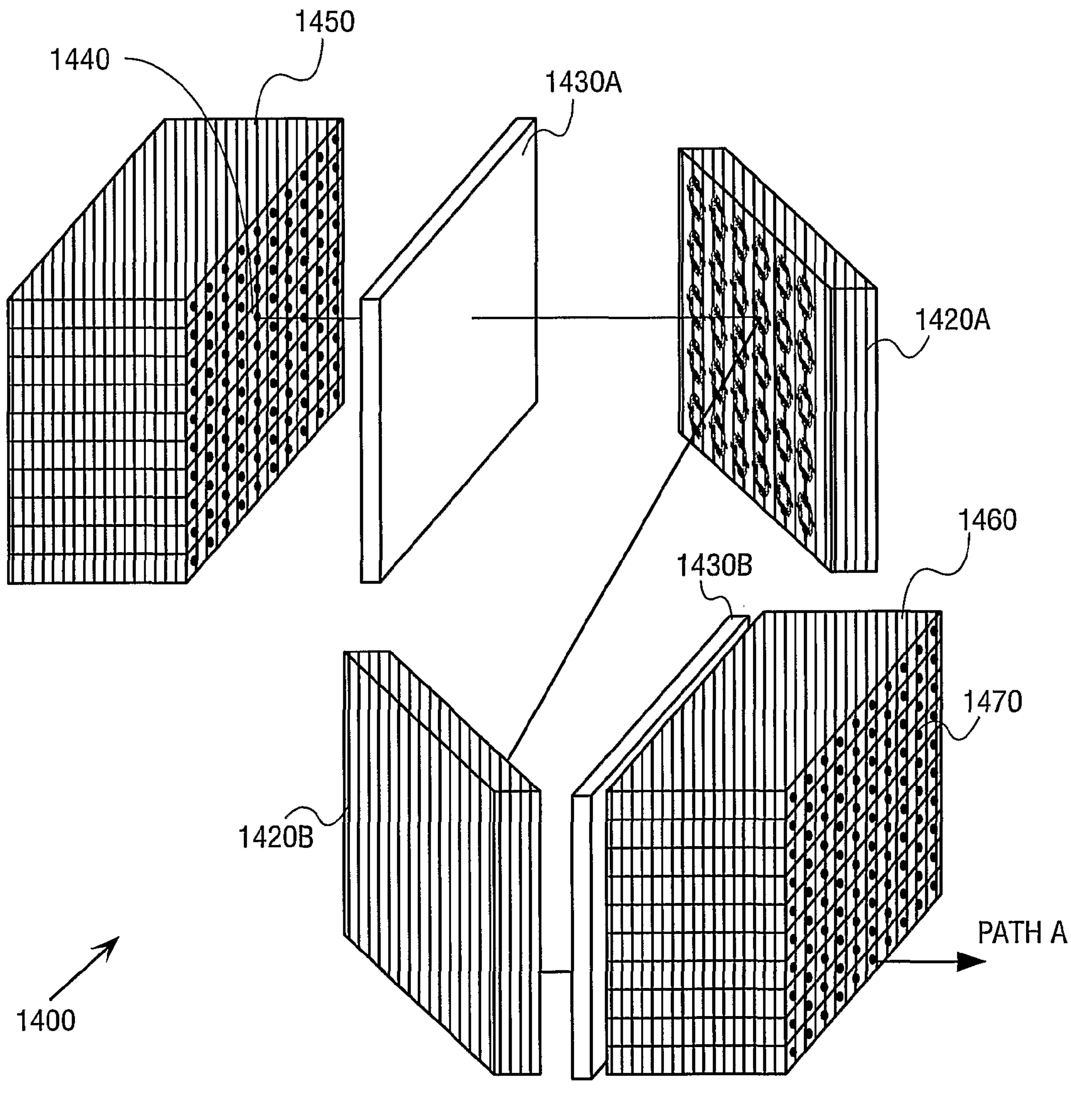


FIG. 14